Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI)

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The STEREO Mission: NASA recently developed a mission concept to place two identically instrumented spacecraft into an orbit about the Sun—one trailing Earth and the other leading Earth. The primary objective of this mission, called STEREO, is to understand the physics of coronal mass ejections (CMEs). By having two spacecraft, CMEs can be observed from two vantage points, and thus three-dimensional information can be gained. The basic physics that expels these plasma clouds into the heliosphere is still not well understood. The role of the magnetic field development in the photosphere and corona and its coupling to the propagation and acceleration processes is crucial to a fuller understanding of these potentially geoeffective events. The STEREO mission combines remote sensing and in situ observations from two distinct views. It is well suited to the exploration of all manifestations of CMEs, both at their initiation and during their propagation to 1 astronomical unit (AU). Major advances in understanding the connection between solar events and their terrestrial response have come when interdisciplinary studies are able to combine data from solar observations with those from the inner heliosphere and from terrestrial observation. In addition to the observations, numerical and analytical modeling analyses will be necessary to connect the observations from the disparate regions.

Why STEREO?: By placing two spacecraft into orbit around the Sun, the STEREO mission removes two difficulties encountered in previous missions that have observed CMEs. A white light coronagraph best observes CMEs that are on the limb; it cannot observe the CME material that would eventually impact Earth. Since each STEREO spacecraft will drift away from the Earth at the rate of 22°/year, CMEs headed toward Earth will be clearly imaged. The second difficulty is that our perception of the corona has been obtained from two-dimensional images. The third dimension has been inferred. Identical instrumentation will be on the two STEREO spacecraft, which will enable simultaneous stereoscopic viewing of quiescent coronal structures as well as dynamic phenomena such as CMEs.

CMEs: Discovered in 1971 by an NRL experiment on-board a NASA satellite, CMEs have become extremely important in understanding the effect of solar emissions on Earth. The NRL Large Angle Spectrometric Coronagraph (LASCO) experiment[1] on the European Space Agency (ESA) and NASA Solar and Heliospheric Observatory (SOHO) has been observing CMEs in unprecedented clarity. Real-time images from LASCO are available on the Web at http://lasco-www.nrl.navy.mil. Figure 1 shows the development of a CME moving through the solar corona on June 2, 1998. This event shows the prototypical three-part structure of a CME—the bright leading material, followed by a dim region, and then complex, twisted bright material. The twisted structure is a solar prominence erupting, carrying magnetic field and ionized material.

SECCHI: In December 1999, NRL was selected by NASA to develop an instrument called the Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) for the STEREO mission. SECCHI is also the name of an Italian astronomer, Angelo Secchi (1818-1878), who pioneered the use of the new medium of photography to solar physics and is considered by some to be the father of astrophysics. SECCHI is designed to explore various manifestations of the CME process with three types of tele-

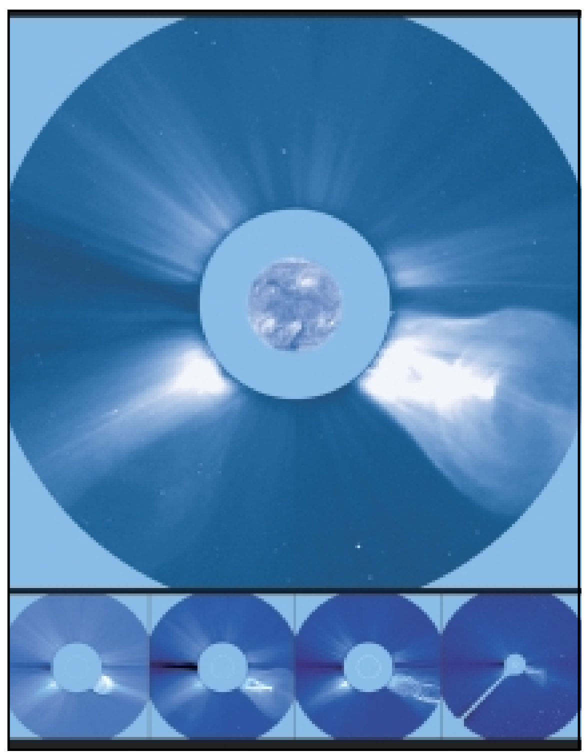

FIGURE 1
Development of a coronal mass ejection moving through the solar corona.

scopes. The first is an extreme ultraviolet (EUV) imager (EUVI) that will image the chromosphere and low corona in four emission lines. The second type, a white light coronagraph, actually is two coronagraphs to explore the inner corona and the outer corona (COR1 and COR2). This function was split into two telescopes because of the large radial gradient in coronal brightness. The third type is a wide field heliospheric imager (HI) to image the inner heliosphere between the Sun and Earth. This region was also split into two telescopes, HI-1 and HI-2, to optimize the stray light requirements.

Scientific Objectives: Figure 2 illustrates the scientific objectives and the approach of SECCHI. These objectives are: What configurations of the corona lead to a CME? What initiates a CME? What accelerates CMEs? and How does a CME interact with the heliosphere? How do CMEs cause space weather disturbances? The EUV, COR1, and COR2 telescopes will address the first two questions. The COR1, COR2, and HI-1 will address the third and fourth questions, and the HI-1 and HI-2 will address the fourth and fifth questions. The final telescope (HI-2) will observe the CME as it impinges on the Earth's atmosphere. The suite of SECCHI telescopes will observe the structures (in stereo) involved in the eruption and will then follow the eruption as it travels through the corona, providing a unique perspective into the physics of CMEs.

Acknowledgments: SECCHI is an international collaboration between the United States (NRL, NASA/Goddard Space Flight Center, the Lockheed Martin Solar and Astrophysics Laboratory, Boston College, Jet Propulsion Laboratory, Smithsonian Astrophysical Observatory, Space Applications International Corporation, Southwest Research Institute, Stanford University), Belgium (Royal Observatory, Centre Spatiale de Liege), France (Institut d'Optique, Institut d'Astrophysique Spatiale, Observatoire de Paris, Laboratoire d'Astronmie Spatiale, University d'Orleans), Germany (Max-Planck-Institut für Aeronomie, Universität Kiel), and the United Kingdom (University of Birmingham, Rutherford Appleton Laboratory, Mullard Space Science Laboratory). In the U.S., the primary sponsor is NASA, but the USAF Space Test Program is supporting the SECCHI integration and test efforts.

[Sponsored by NASA and USAF/STP]

Reference

[1] G.E. Brueckner, R.A. Howard, K.P. Dere, *et al.*, "The Large Angle Spectroscopic Coronagraph (LASCO)," *Solar Phys.* **162**, 357-402 [1995].

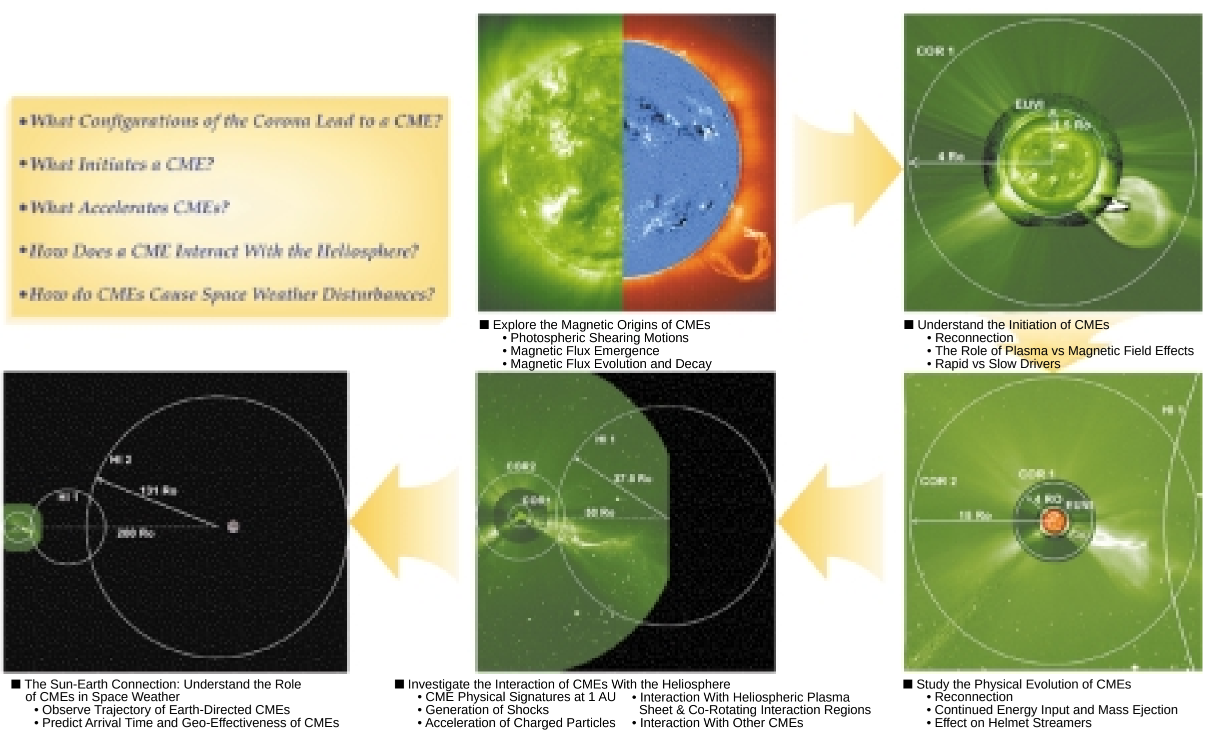

FIGURE 2
SECCHI exploration of CMEs and the heliosphere on STEREO.

FAME Radiometric Data Requirements and Processing

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Introduction: The Full-sky Astrometric Mapping Explorer (FAME) spacecraft is being integrated by the Naval Center for Space Technology (NCST) for launch in 2004. FAME is a NASA Medium-Class Explorers mission. Its Principal Investigator is located at the U.S. Naval Observatory. The goal of the FAME mission is to create new star catalogs of unprecedented accuracy. A significant challenge to meeting this goal is to determine the velocity of the satellite to within 1 centimeter per second with a minimum of tracking data. (Collection of tracking data can impact the return of science data.) The Astrodynamics and Space Applications Office (ASAO), Code 8103, is providing support for mission planning, operations, and science data reduction. In preparation for flight operations, Code 8103 analyzed the FAME orbit and determined the amount of tracking data required from NRL's Blossom Point (Maryland) Tracking Facility to meet the velocity knowledge requirement. This process demonstrates an important capability within NRL and NCST to design, analyze, track, and compute satellite orbits.

The Orbit: The FAME operational orbit is a geosynchronous orbit at 105 degrees west longitude, inclined to the Earth equator at 28.7 degrees. The ground station for mission operations is located near NRL in southern Maryland at Blossom Point. Figure 3 shows the ground track for the FAME spacecraft as well as the location of the Blossom Point ground station. The pink line shows the field of view for the ground station to satellites at geosynchronous altitude. The selected orbit provides for continuous coverage to the ground station. This orbit is stable and will remain within a few degrees of its original longitude over the lifetime of FAME.

Code 8103 in NCST is providing the definitive orbital ephemeris for FAME. The ephemeris contains the position and velocity of the spacecraft with respect to the center of the Earth over time. The FAME science team has allocated a portion of the error budget for FAME science data reduction to the spacecraft velocity knowledge. This knowledge is important for reduction of the data in that it allows the science team to correct for the abberation in the FAME measurements due to spacecraft motion. The allocation for velocity error is 1 cm/s. Code 8103 has determined the minimum amount and types of tracking data that meet this requirement. Minimizing the amount of tracking data for FAME is valuable because the collection of active ranging measurements interrupts the downlink of science data.

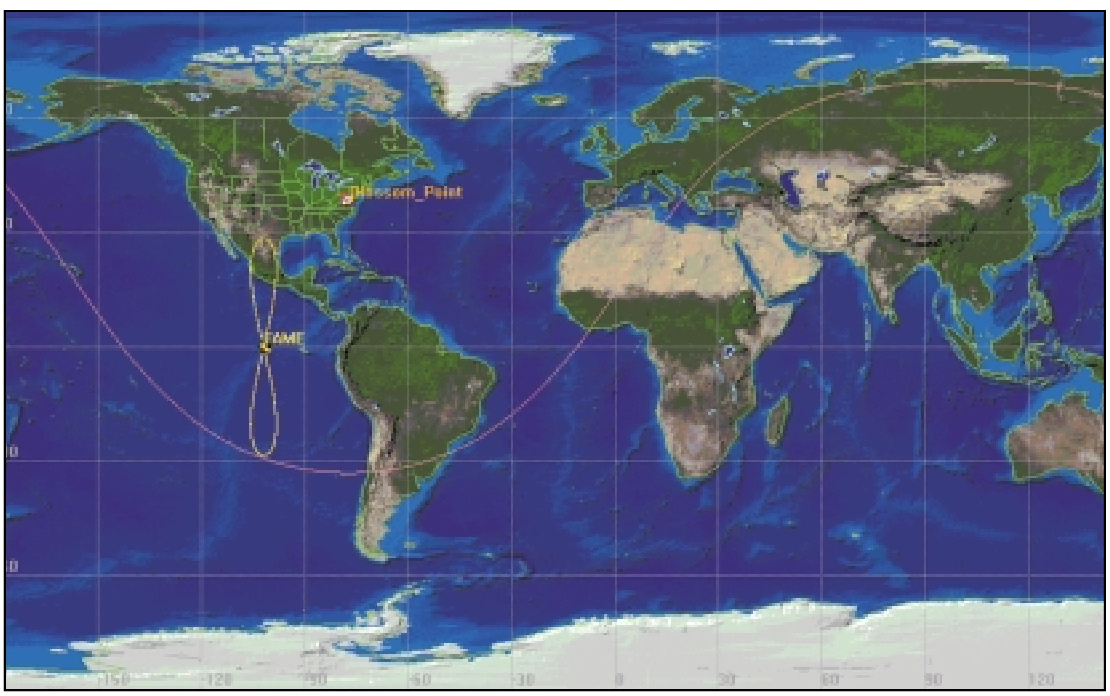

FIGURE 3
Graphical representation of nominal FAME ground track, tracking station, and tracking station field of view.

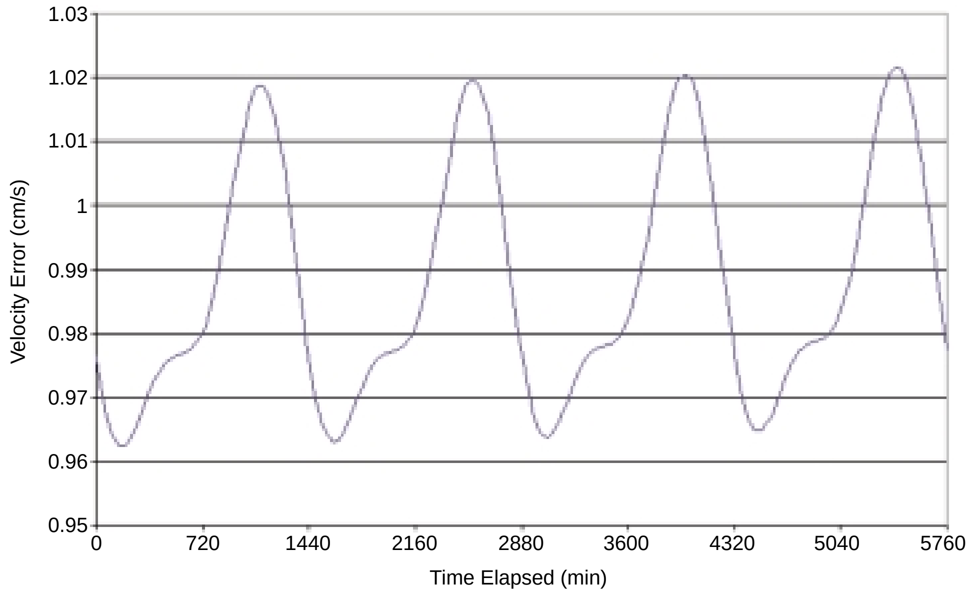

FIGURE 4
Plot of estimated FAME velocity error vs time over 4 days.

Analysis: Covariance analysis was used to determine the system tracking requirements. The covariance analysis tool models the system, the measurements, and the errors according to user-defined parameters. An iterative process was performed in which various satellite orbits, ground stations, measurement types, measurement duration, and measurement intervals were modeled to determine the most likely operations scenario for FAME. Various measurement errors were modeled to determine the sensitivity of the orbit determination (OD) solution to the error levels. The results of the analysis show that with FAME in a 105-degree west longitude geosynchronous orbit inclined at 28.7 degrees, and a single ground station located at Blossom Point, Maryland, the FAME velocity knowledge requirements can be met. The covariance analysis was then verified using a Monte-Carlo simulation using a similar system and tracking scheme. The measurement data used to determine the FAME orbit are one hour of Doppler range rate data three times per day and ten minutes of active range data three times per day. Figure 4 is a plot of the expected velocity errors. Although the figure shows that the expected velocity will exceed the 1 cm/s velocity requirement over a portion of the orbit, this was deemed acceptable by the science team because the covariance analysis uses 3-s measurement and model errors.

Summary: The next step in the orbit determination validation process will be to process simulated range and range rate data generated by the covariance analysis tool using the OD software. Simulated measurements will be processed using NRL's OCEAN software (Orbit Covariance and Estimation Analysis). OCEAN is a state-of-the-art, sub-meter-level, multi-satellite orbit determination, ephemeris propagation, and timing calibration software tool. After FAME is launched, OCEAN will produce the definitive orbits used by the science team to correct the astrometric measurements. The level of ephemeris accuracy will allow the abberation due to spacecraft motion to be removed.

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Interim Control Module Night Sky Attitude Determination Test

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The Interim Control Module (ICM) was designed to provide attitude determination and control (ADAC) and reboost capabilities for the International Space Station (ISS). An end-to-end attitude determination test was conducted to verify the attitude determination requirements and prove out the electrical and software interfaces to the ADAC sensors.

Figure 5 shows the ICM attached to the ISS. The cones depict the bright-object keep-out zone for each of the two star tracker cameras (STC). The ICM flight

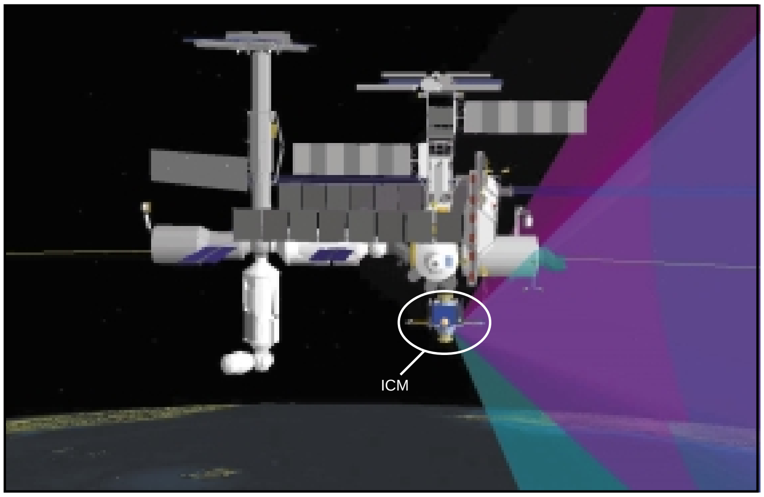
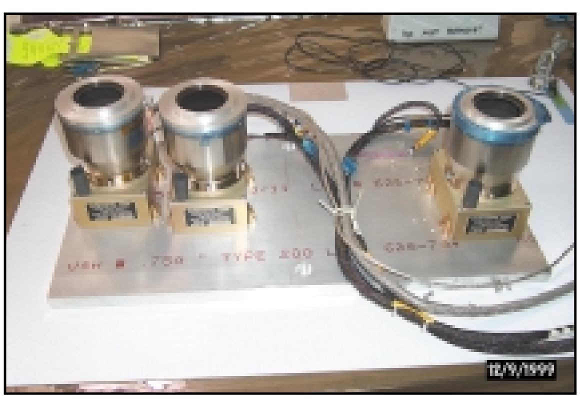


FIGURE 5
ICM attached to International Space Station.

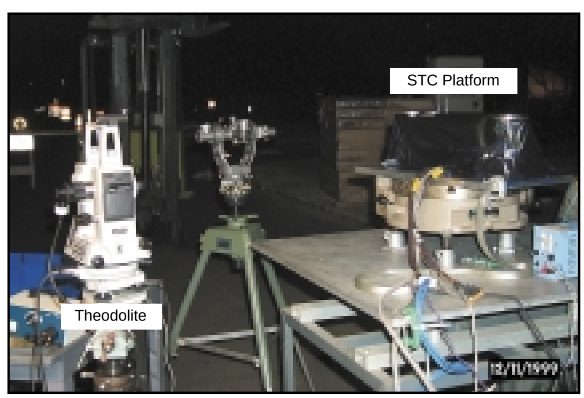
computer processes images from the STCs to determine the ISS orientation (attitude) based on the observed star pattern. The ADAC Kalman filter software blends the STC attitude solutions with Inertial Measurement Unit (IMU) gyroscope readings. The gyroscope angular rate measurements are used to propagate the attitude estimate between STC updates. The Kalman filter uses the STC updates to compute gyroscope bias estimates. The biases are subtracted out to minimize loss of attitude estimate precision during STC outage periods caused by Earth or Sun intrusion. The gyroscope measurements are further used by the ADAC software to provide rate damping for convergent, stable closed-loop control of the ISS attitude.

Test Description: The main goal of the test was to verify attitude knowledge accuracy requirements. The mature state of development of the ICM also provided an opportunity to verify the electrical and software interfaces to the flight sensors and processing electronics as well as the attitude determination Kalman filter processing.

The STCs were mounted to a test platform outside the NCST Payload Checkout Facility;[1] the assembled ICM structure, electronics deck, and IMUs remained inside. To arrive at the “truth” attitude against which the attitude solution accuracy would be judged, the STC mounting platform was leveled with respect to the local gravitational force vector. It was precisely aligned in azimuth using Polaris as a reference and making use of the STC optical alignment cube. Figure 6 shows the test setup. With the STCs in a known orientation with respect to the local reference frame, the predicted inertial attitude was computed by factoring in the latitude and longitude

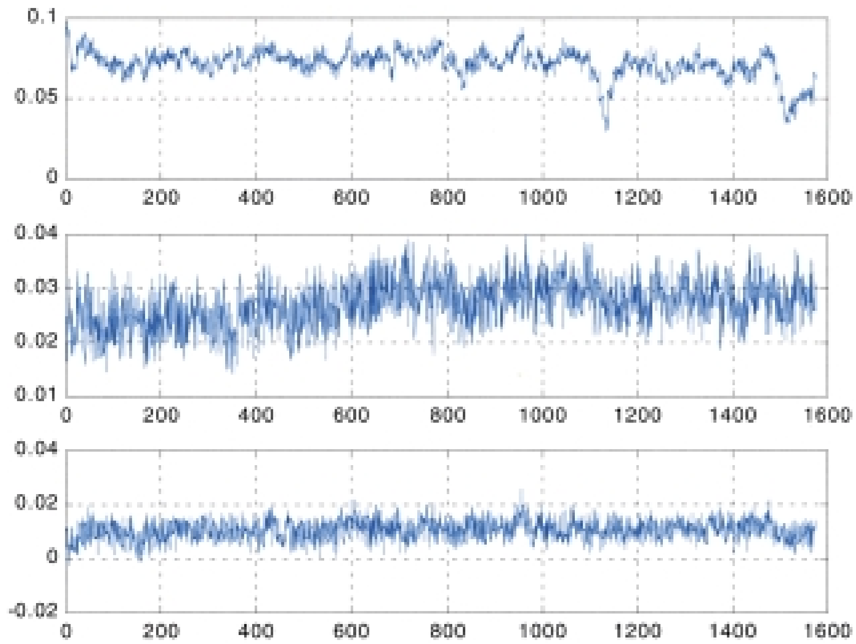


(a) STCs on mounting platform

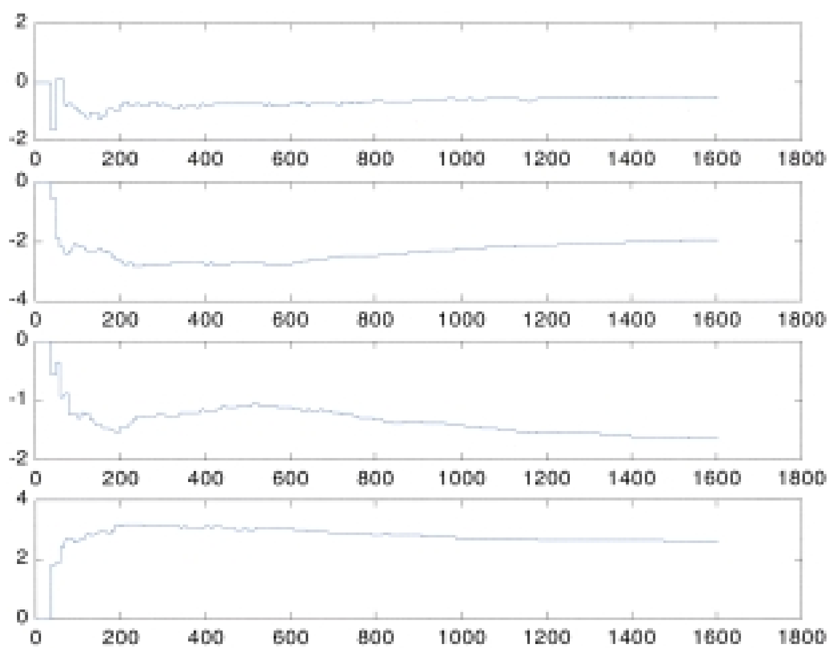


(b) Alignment configuration

FIGURE 6
Night sky test setup.



(a) Attitude error with respect to predicted attitude



(b) Gyro bias estimates

FIGURE 7
Kalman filter performance.

of the test site and the time of the STC image collection. The attitude of the ICM structure was estimated using several minutes of data collected from the IMU. The components of Earth rate sensed in each of three orthogonally mounted gyroscopes uniquely identified its orientation with respect to the local reference frame. This information was then used in the attitude determination Kalman filter so that the sensor measurements from the STCs and the IMUs were provided to the filter in a consistent reference frame.

Results: The test verified the required accuracy of better than 0.1 degrees per axis (Fig. 7(a)).[2] The validity of the alignment correction terms relating the camera CCD frame to the optical alignment cube were also verified. The attitude determination Kalman filter processing results (Fig. 7(b)) verified correct polarity, convergence, and propagation behavior.

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[Sponsored by NASA]

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[1] "ICM ACS Integrated Attitude Determination Night Sky Test Procedure, SSD-TD-IM058," NRL, Naval Center for Space Technology, 9 December 1998.

[2] "ICM ACS Integrated Attitude Determination Night Sky Test Report, SSD-TR-IM116," NRL, Naval Center for Space Technology, 22 May 2000.